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NASA PROGRAM APOLLO WORKING PAPER NO. 1318

DEVELOPMENT AND QUALIFICATION OF THE APOLLO SEA DYE MARKER

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS
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CONTENTS

TABLES

FIGURES

DEVELOPMENT AND QUALIFICATION OF THE APOLLO SEA DYE MARKER

By R. W. Bricker, J. J. Liddell, and
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SUMMARY

In-house development was undertaken to provide a 12-hour life sea dye marker as Government furnished equipment for Apollo spacecraft. An approach was undertaken utilizing a canister with fluorescein dye powder dispensed through small orifices. Twelve-hour dye life has been verified in Gulf of Mexico tests on Apollo boilerplates 1215 and 29, and on S/C 007.

INTRODUCTION

The Development and Evaluation Section of the Mechanical Systems Branch (now the Structures Test Section of the Structures and Materials Branch) conducted an in-house test program to develop an Apollo dye marker. Following the development program, a qualification test program was conducted to qualify the marker for Apollo Block I and Block II spacecraft.

DESCRIPTION

Equipment

A test apparatus was fabricated from components existing in the Mechanical Systems Laboratory (fig. 1). The objective of the apparatus was to impose dynamic action on a dye canister in a laboratory water tank similar to that seen by a dye canister on the Apollo spacecraft (S/C) during average sea conditions. The test apparatus can impose a maximum stroke of 20 inches on the dye canister with a cycle frequency of from 100 to 300 cpm. A correlation between the test apparatus and tests in the Gulf of Mexico with an Apollo boilerplate was achieved by using the same canister for each test and adjusting the dynamic conditions

of the tank until similar dye lives were obtained. Fresh water was circulated through the test tank at a rate of approximately 600 gallons per hour.

Tests

Table I lists correlation tests, development tests, and qualification tests conducted in the test tank and in the Gulf of Mexico. At the initiation of the development program, only one test that could be used for the correlation of tank tests had been conducted in the Gulf of Mexico. The canister tested in the Gulf was smaller than the maximum space available in the NAA Apollo Sea Dye Marker/Swimmer Umbilical Interphone Unit. Dye life in the Gulf test was approximately 5-1/2 hours. The same canister was used for initial correlation of tank tests on April 22. The prototype canister referred to in table I was an interim model designed in support of S/C 011 to make optimum use of the available space in the NAA dye-cake container except for the tapered snout utilized in the flight type. The prototype canister is to the right in figure 2, and the canister on the left is the flight type. Various tests were conducted with the prototype canister from April 22 to April 27 to determine the proper orifice size to achieve a 12-hour dye life. The uranine water-soluble dye (sodium fluorescein), furnished by Fisher Chemical Company, proved to be drier and more consistent in performance than other available dyes. Since the loosely packed fluorescein dye had a large void factor, the dye was pressure-packed to achieve greater packing density. A packing pressure of 1000 psi increased the quantity of dye by 20 percent. A test conducted on April 22 indicated that pressure packing the dye greatly reduced the initial dispersion rate with this type dye. This appeared to be due to the large moisture content of this dye which was an industrial grade.

On April 29, a test was conducted in the Gulf of Mexico with a flight-type canister that had been subjected to vibration and shock. The two orifices were also enlarged to an 0.063-inch diameter after a short test the preceding day had indicated that the initial dispersion was very poor. The ultimate slick size was quite large; however, the dye life was 4-1/2 hours short of the required time. On close examination after retrieval, the canister was found to be cracked. The fracture was determined to be the result of an inadequate packing fixture. The fixture was improved and a correlation test was conducted in the test tank on May 3. The results of this and the previous test indicated that the correlation was incorrect. The cycle frequency and stroke were increased, and another tank test versus a Gulf of Mexico correlation test was conducted on May 4 with the undersized canister loosely packed with Allied fluorescein dye. The dye life of 4-1/2 hours appeared to provide a more conservative correlation with the Gulf test.

On May 6, a tank test was conducted with the orifice size reduced from a 0.063- to a 0.046-inch diameter. In addition, a loose baffle was placed at the nose end of the canister in an attempt to prevent tight packing of dye in the nose to improve the initial dispersion from the nose end. The packing pressure was increased to 2000 psi and a temporary switch was made to the Allied Chemical Company dye due to the non-availability of Fisher dye. The weight of packed dye increased approximately 5-1/2 percent with some loss in volume due to the addition of the baffle. Results of this test indicated very little improvement in initial dispersion and an inadequate dye life.

A quantity of the Allied Chemical Company dye was dried in a vacuum oven until most of the free moisture was removed. Over 1 ounce of moisture was removed per pound of dye. Tank tests conducted with this dye on May 7 indicated the drying significantly increased the initial dispersion and total dye life. The Fisher dye used for most tests was of laboratory grade and was received in a dry condition.

Tank tests through May 8 had not produced adequate initial dispersion or the required 12-hour dye life, despite the addition of the baffle and reduction in orifice size. As a result of the second test on May 8, the orifice size was reduced to an 0.0295-inch diameter with both orifices placed in one end (fig. 3). The lower location of the orifices provided a much improved initial dispersion, apparently due to the effect of a slight head of dye solution which caused a spurting action from the orifices.

Tank tests on May 10 and 11 indicated that this approach provided excellent initial dispersion and a dye life of 13 to 14 hours. On May 24, tests were conducted in the Gulf of Mexico on BP-1215, and a dye slick of approximately 40 000 square feet was produced with a life of 13 hours. The sea state was negligible for this test, indicating the need for an additional sea test since in most cases some sea state would exist in the landing area.

An improved packing fixture was fabricated permitting utilization of a packing pressure of 4000 psi which was double that previously used. This increased the capacity approximately 7 percent (figs. 4 and 5).

A tank test was conducted June 3 to evaluate the higher packing pressure. An unexpected reduction of dye life occurred with a test duration of only 10 hours compared to the preceding test duration of 13 to 14 hours.

On June 9, a development test was conducted in the Gulf of Mexico on BP-29. The sea state was almost zero throughout the day and approximately 50 percent of the dye remained after 12 hours. The lesser dynamic

action of BP-29 as compared to BP-1215 probably contributed to the reduced dye dispersion.

In an attempt to qualify a sea dye marker, a flight-type canister was exposed to humidity, acceleration, vibration, thermal/vacuum, and shock as specified in Qualification Test Procedure, Report No. SMD-MSB-A5, Revision B. At the completion of these tests, a small crack was detected in a weld area of the canister but did not appear large enough to effect the dye life. On July 19 this canister was tested in the Gulf of Mexico on Boilerplate 29. The initial dispersion was good and built up to 35 000 square feet. The slick reduced in size during the afternoon due to a decrease in wind conditions and sea state. At the termination of the test, 15 ounces of dye remained in the canister. The canister had been installed upside down tending to decrease the dispersion.

As a result of the small crack, an improved welding technique was applied including a bead on the inside of the canister to provide a stronger seam.

On August 5, vibration and shock tests were conducted on the improved canister in accordance with Qualification Test Procedure, Report No. SMD-MSB-A5, Revision B.

It was decided that the humidity, acceleration, and thermal/vacuum had no effect on the structural integrity of the canister; therefore, these tests were omitted. A close inspection of this canister, including dye penetrant techniques, revealed that the welds were crack free.

Packing Techniques

In addition to the high-pressure dry packing, selected as the optimum technique, several other approaches were tried. Since the dye is soluble in water, alcohol, and certain other liquids, it was thought that the void factor could be reduced by making a paste of liquid and dye and then packing this material. With either a water or alcohol mix, the paste set up hard within a few seconds to a minute after the mixing time, making this approach quite difficult. Canisters packed in this manner, in addition to containing an unknown quantity of liquid, did not contain as much dye as those packed dry. This procedure required several hours to accomplish, whereas the dry packing took less than 1 hour.

The prime contractor for Apollo utilized a dye cake approach which consisted of mixing the dye with a solvent and binder. The cake was then put through a curing cycle at temperatures up to 250° F for a period of 56 hours at a pressure of 4000 psi. The resulting cake was then trimmed to size, wrapped with a layer of polyvinyl alcohol plastic and

then hand sewn into a nylon mesh bag. Another layer of polyvinyl alcohol was placed around the nylon and sealed. Since the polyvinyl alcohol is water soluble, the resulting cake was sensitive to handling and humidity conditions. In addition, X-rays of the cakes indicated large cracks running the full length and width of the cake, contributing to an unpredictable dye life due to the resultant uncontrolled surface area. The binder also may immobilize some of the dye letting it sink without contributing to the dye slick. The quantity of the dye provided by this approach is 24 ounces with a binder weight of approximately 6 ounces for a total cake weight of approximately 33 ounces, including wrappings and baffle. In four tests conducted on Apollo boilerplates in the Gulf of Mexico, dye life varied from an initial 3-1/2 hours to 8 hours. Slick size varied from 40 000 square feet to inadequate. The dye cake is placed in a holder (fig. 6) that is attached to the upper deck of the spacecraft with a 96-inch tether. The dye container is deployed after landing, and dye dispersion takes place due to the rocking motion of the spacecraft. The GFE canister was configured to fit into the canister designed originally for the dye cake to preclude the necessity for any changes having to be made by the prime contractor. Total weight of the GFE canister and dye is approximately 34 ounces. Approximately 28 ounces of this weight consists of dye.

CONCLUSIONS

1. The use of the dye-cake technique for a dye marker does not provide consistent dispersion due to the varying surface area caused by cracking and varying density of the cake.

2. The dye cake technique requires extensive preparation and is sensitive to handling and environment.

3. The dye canister with orifices provides a uniform and repeatable dispersion rate.

4. By pressure packing, a substantial increase in actual dye powder by weight can be packed into the same volume required for a dye cake.

5. The canister technique is not sensitive to humidity, ultra-high vacuum, or other spacecraft environments.

6. Unwetted dye disperses more uniformly and permits more dye to be packed into the same volume.

7. A minimum of 3 ounces of fluorescein dye per hour is required to give an adequate dye slick. Four ounces of dye per hour will provide a more adequate dye slick since observers have indicated that a slick size of 40 000 square feet or larger is desirable.

RECOMMENDATIONS

1. That Apollo and future spacecraft requiring a dye marker as a recovery aid utilize the canister-with-orifices approach.

2. That dye be packed in the canister at a pressure of 4000 psi or greater.

3. That either laboratory-grade dye be used or the dye be vacuum dried.

4. That sufficient dye be packed in the canister to provide a dispersion rate of at least 3 ounces per hour.

TABLE I.- DYE CANISTER DEVELOPMENTAL TESTS

Date	Dye manufacturer	Canister type	Packing technique	Hole configuration	Test dynamics	Initial dispersion	Uniformity during test	Duration of adequate dispersion, hr:min	Remarks
4/11/66	Allied Chemical Co.	LRD undersize	Hand packed 18.25 oz	One hole each end 0.063-in. diameter	15 cpm 12-in. stroke changed to 30 cpm after 30 min	Very poor first hr	Inadequate during most of test	7:20	Approximately 10 oz of unwet dye removed from canister after test
4/20/66	Allied Chemical Co.	LRD undersize	Loose packed 16 oz	One hole each end 0.063-in. diameter	24 cpm 18-in. stroke	Strong	Strong	1:40	Test dynamics too fast to correlate with 5 hr 30 min Gulf Test
4/21/66	Allied Cheminal Co.	LRD undersize	Loose packed 16 oz	One hole each end 0.063-in. diameter	15 cpm 12-in. stroke	Good	Strong	7:00	Chosen as adequate correlation for further testing
4/22/66	Allied Chemical Co.	LRD undersize	1000 psi 19.3 oz	One hole each end 0.063-in. diameter	15 cpm 12-in. stroke	Poor first 4 hr	Poor	9:00	Decision to top of packed dye with loose dye for last 1/8 in. to improve initial dispersion
4/23/66	Allied Chemical Co.	Prototype	Approximately 600 psi 22 oz	One hole each end, top left at filling end 0.070-in. diameter	15 cpm 12-in. stroke	Poor	Weak beginning, strong peak	11:00	Hole size too large for adequate dye life
4/24/66	Fisher Scientific Co.	Prototype	1000 psi 24.2 oz	One hole each end, top left at filling end 0.063-in. diameter	15 cpm 12-in. stroke	Good after 15 min	Strong peak	11:00	Smaller hole size required to obtain required life
4/27/66	Fisher Scientific Co.	Prototype	1000 psi 24.6 oz	One hole each end, top left at filling end 0.059-in. diameter	15 cpm 12-in. stroke	Poor	Buildup took over 1 hr	13:00	Chosen for Gulf Test
4/29/66	Fisher Scientific Co.	Qualification Flight S/N 202	1000 psi 25.3 oz	One hole each end, top left at filling end 0.063-in. diameter	Tested in Gulf, 10- to 12-knot winds	Poor	Buildup to 110 000 sq ft, slick, 6 hr	7:30	Holes enlarged to 0.063 in. after short test in Gulf 4/29/66 indicated poor initial dispersion

TABLE I.- DYE CANISTER DEVELOPMENTAL TESTS - Continued

Date	Dye manufacturer	Canister type	Packing technique	Hole configuration	Test dynamics	Initial dispersion	Uniformity during test	Duration of adequate dispersion, hr:min	Remarks
5/3/66	Fisher Scientific Co.	Qualification Flight S/N 202	1000 psi	One hole each end, top left at filling end 0.063-in. diameter	15 cpm 12-in. stroke	Good	Buildup to peak	11:00	Test run for correlation due to larger hole size, crack and hole through sponge. Correlation too slow
5/4/66	Allied Chemical Co.	Qualification Flight S/N 202	Loose packed 16.25 oz	One hole each end 0.063-in. diameter	22 cpm 14-in. stroke	Good	Good	4:30	Test run to speed up tank test for proper correlation with Gulf tests
5/6/66	Allied Chemical Co.	Prototype with aluminum baffle	2000 psi loose in nose and at filling end 26.91 oz	One hole each end, bottom left at filling 0.046-in. diameter	22 cpm 14-in. stroke end	Poor start from nose end	Slow buildup	8:30	Baffle deforming into nose packs loose dye
5/7/66	Allied Chemical Co. dried. Fisher loose at both ends	Prototype with aluminum baffle	2000 psi loose in nose and at filling end 24 oz	One hole each end, up at filling end 0.046-in. diameter	22 cpm 14-in. stroke	Very good	Very strong	5:00	Vacuum drying of dye apparently sped up dispersion significantly
5/8/66	Allied Chemical Co.	Prototype with stainless steel baffle	2000 psi loose both ends 25.98 oz	One hole each end, upper left at filling end 0.046-in. diameter	22 cpm 14-in. stroke	Fair	Good after first hr	8:30	
5/8/66	Fisher Scientific Co.	Prototype with stainless steel baffle	2000 psi loose both ends 25.58 oz	One hole each end, top left at filling end 0.039-in. diameter	22 cpm 14-in. stroke	Good from both ends	Dispersion inadequate at 2 hr 30 min	5:00	After 2 hr 45 min canister was turned with hole down due to inadequate dispersion. Dispersion immediately increased to high level. Test terminated after 5 additional hr. Fifty percent of dye still in canister

TABLE I.- DYE CANISTER DEVELOPMENTAL TESTS - Continued

Date	Dye manufacturer	Canister type	Packing technique	Hole configuration	Test dynamics	Initial dispersion	Uniformity during test	Duration of adequate dispersion, hr:min	Remarks
5/9/66	Fisher Scientific Co.	Flight type S/N 202	2000 psi loose at filling end only 26.96 oz	Two holes both in filling end, one high 0.0295-in. diameter	22 cpm 14-in. stroke	Very good	Excellent and uniform throughout test	14:00	This approach gave much better initial dispersion without permitting the runaway peak due to flow through the canister. Location of lower hole gives good initial dispersion due to greater head effect
5/10/66	Fisher Scientific Co.	Flight type S/N 202	2000 psi loose at filling end only 26.97 oz	Two holes same end, both low 0.0295-in. diameter	22 cpm 14-in. stroke	Excellent after 5 min	Excellent and uniform throughout test	14:30	Initial dispersion excellent without reducing total life will be approach used for Gulf Test for S/C 012
5/11/66	Allied Chemical Co. Vacuum dried	Prototype	2000 psi loose at filling end only 26.2 oz	Two holes same end, both low 0.0295-in. diameter	22 cpm 14-in. stroke	Excellent after 5 min	Excellent and uniform throughout test	13:30	Test indicates holes are controlling dispersion eliminating effect of dye manufacturing and moisture content
5/24/66	Fisher Scientific Co.	Flight	2000 psi loose at filling end only 26.0 oz	Two holes same end, both low 0.029-in. diameter	BP 1215 19 cpm Sea wind Velocity 3 hr-0 knot 6 hr-4 knot 10 hr-8 knot	Slow buildup to 4500 sq ft in 1.5 hr Average dispersion 2 oz/hr	Good slick size; buildup to 40 000 sq ft	13:00	Slick size not as large as desired but is maximum obtainable consistent with quantity of dye at 12-hr life
6/3/66	Fisher Scientific Co.	Flight	4000 psi loose at filling end only 28.96 oz	Two holes same end, both low 0.0295-in. diameter	22 cpm 14-in. stroke	Spurting from both holes. Buildup to strong solution in 2 hr	Good	10:00	Reduction in life with more dye unexpected. Higher pressure not retarding dispersion

TABLE I.- DYE CANISTER DEVELOPMENTAL TESTS - Concluded

Date	Dye manufacturer	Canister type	Packing technique	Hole configuration	Test dynamics	Initial dispersion	Uniformity during test	Duration of adequate dispersion, hr:min	Remarks
6/9/66	Fisher Scientific Co.	Block I Development	4000 psi loose at filling end only 29.67 oz	Two holes same end, both low 0.0295-in. diameter	BP 29 Sea 0 Frequency less than BP 1215	Slow	Fair	12:00	More than 50 percent dye remaining after 12 hr
7/19/66	Fisher Scientific Co.	Block I and II Qualification	4000 psi loose at filling end only 29.4 oz	Two holes same end, both low 0.0295-in. diameter	BP 29 Sea 1 wind velocity 1 to 5 knot	Very good	Tapered off from 35 000 ft to small slick in p.m.	11:30	Dye canister was installed upside down (holes up) which would slow dispersion, 15 oz dye remaining after test
10/2/66	Fisher Scientific Co.	Block I and II Development S/N 7	4000 psi loose at filling end 27.72 oz	Two holes same end, both low 0.0295-in. diameter	S/C 007 19 cpm Sea 2 Wind 7 knot	Marginal 19 600 sq ft	Uniform throughout test	10:00	Dye did not meet test requirements concerning slick size 12 oz dye left in canister
10/6/66	Fisher Scientific Co.	Block I and II S/N 2	4000 psi loose at filling end. Sponge wetted and impregnated with dye, dried 28 oz	Two holes same end, both low 0.035-in. diameter	20 cpm 14-in. stroke	Strong buildup in 2 hr	Excellent and uniform throughout test	12:00	All dye used
10/10/66	Fisher Scientific Co.	Block I and II S/N 2	4000 psi loose at filling end. Sponge wetted and impregnated with dye, dried 28.3 oz	Two holes same end, both low 0.035-in. diameter	22 cpm 14-in. stroke	Strong initial dispersion	Excellent	10:00	All dye used
10/12/66	Fisher Scientific Co.	Block I and II S/N 2	27.8 oz	Two holes same end, both low 0.035-in. diameter	22 cpm 14-in. stroke	Good, less than previous test due to one orifice being slightly restricted	Good	10:30	All dye used

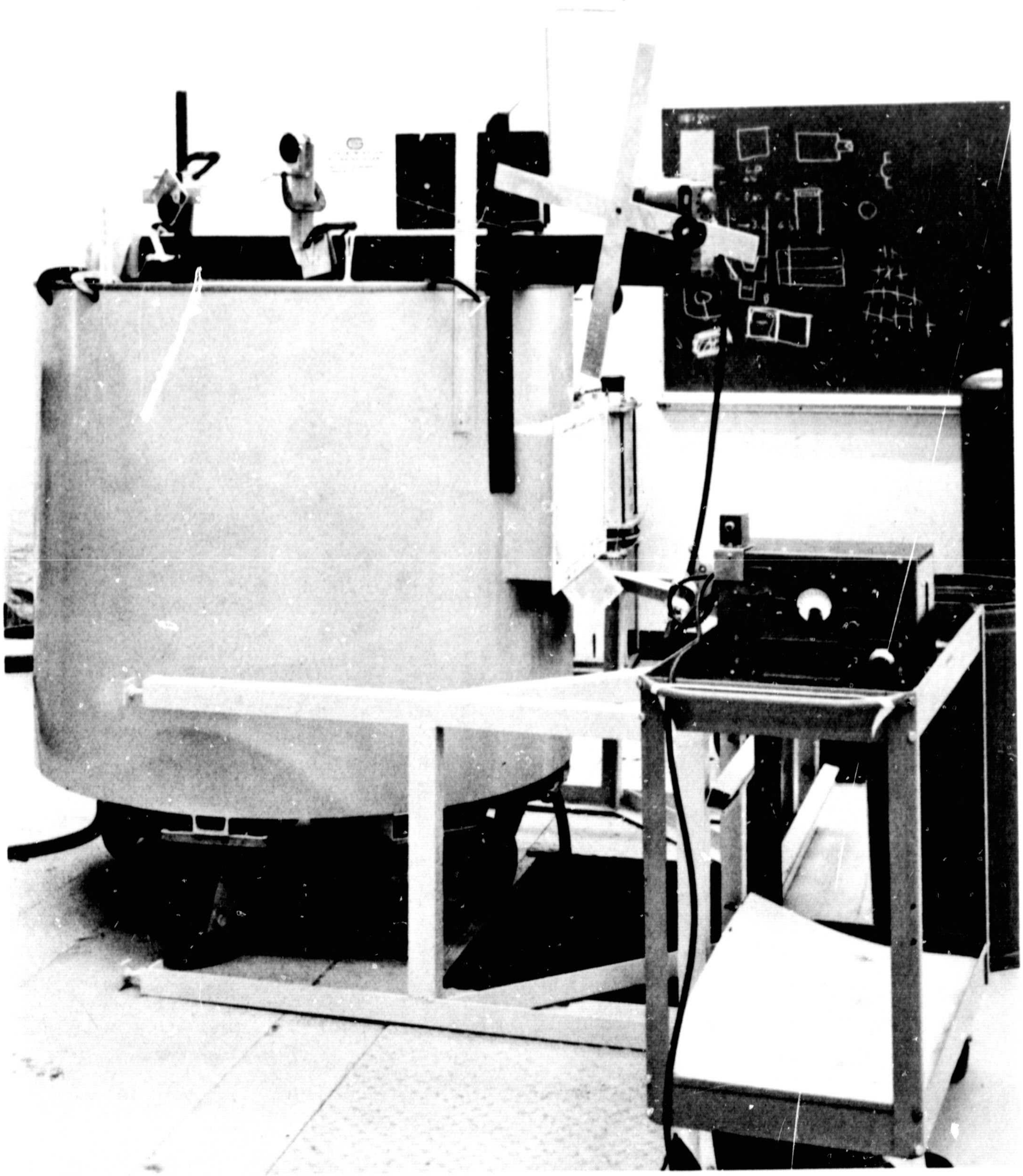

Figure 1.- Dye canister tank test apparatus.

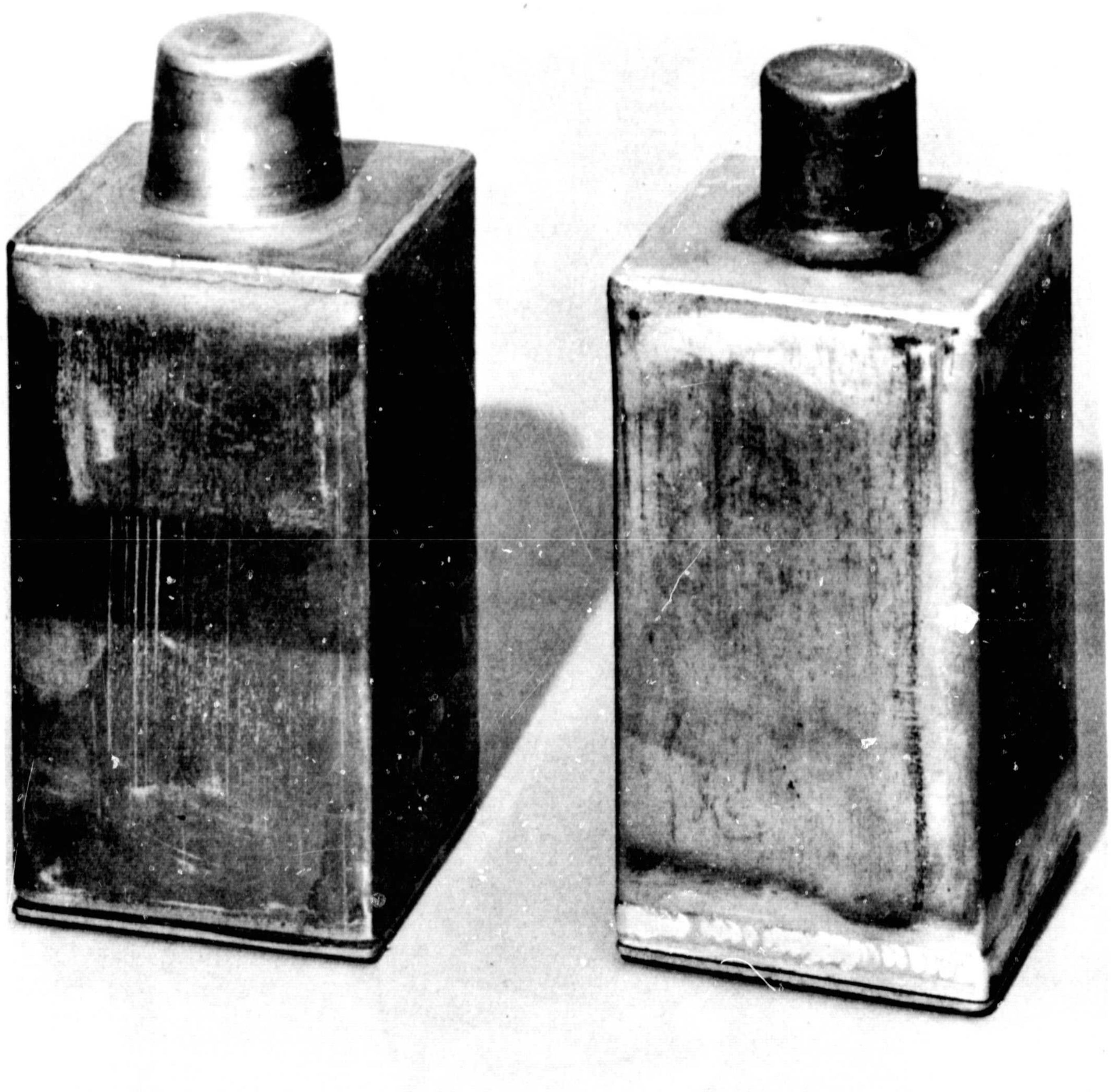

Figure 2.- Flight type and prototype dye canisters.

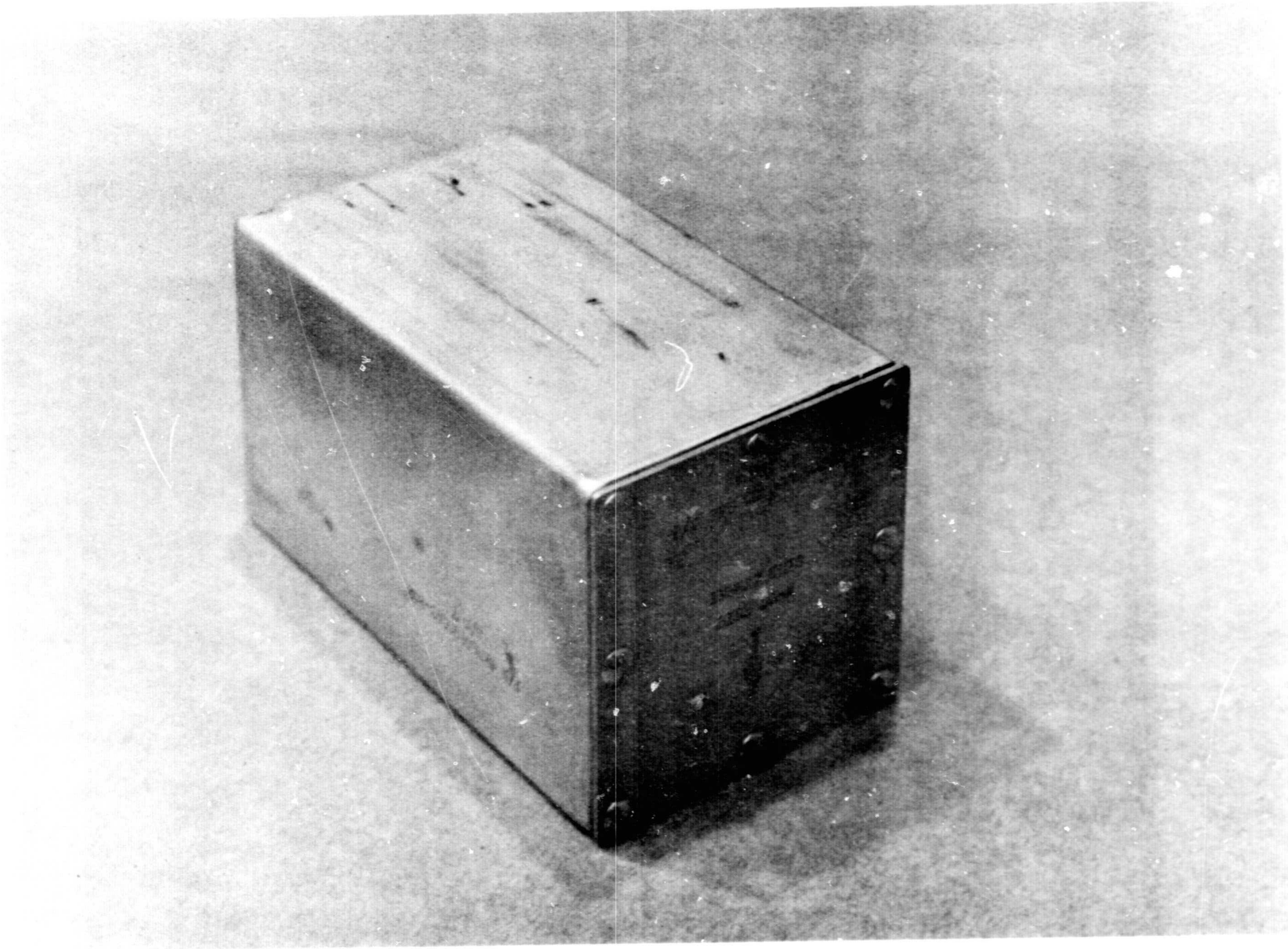

Figure 3.- Dye canister orifice location.

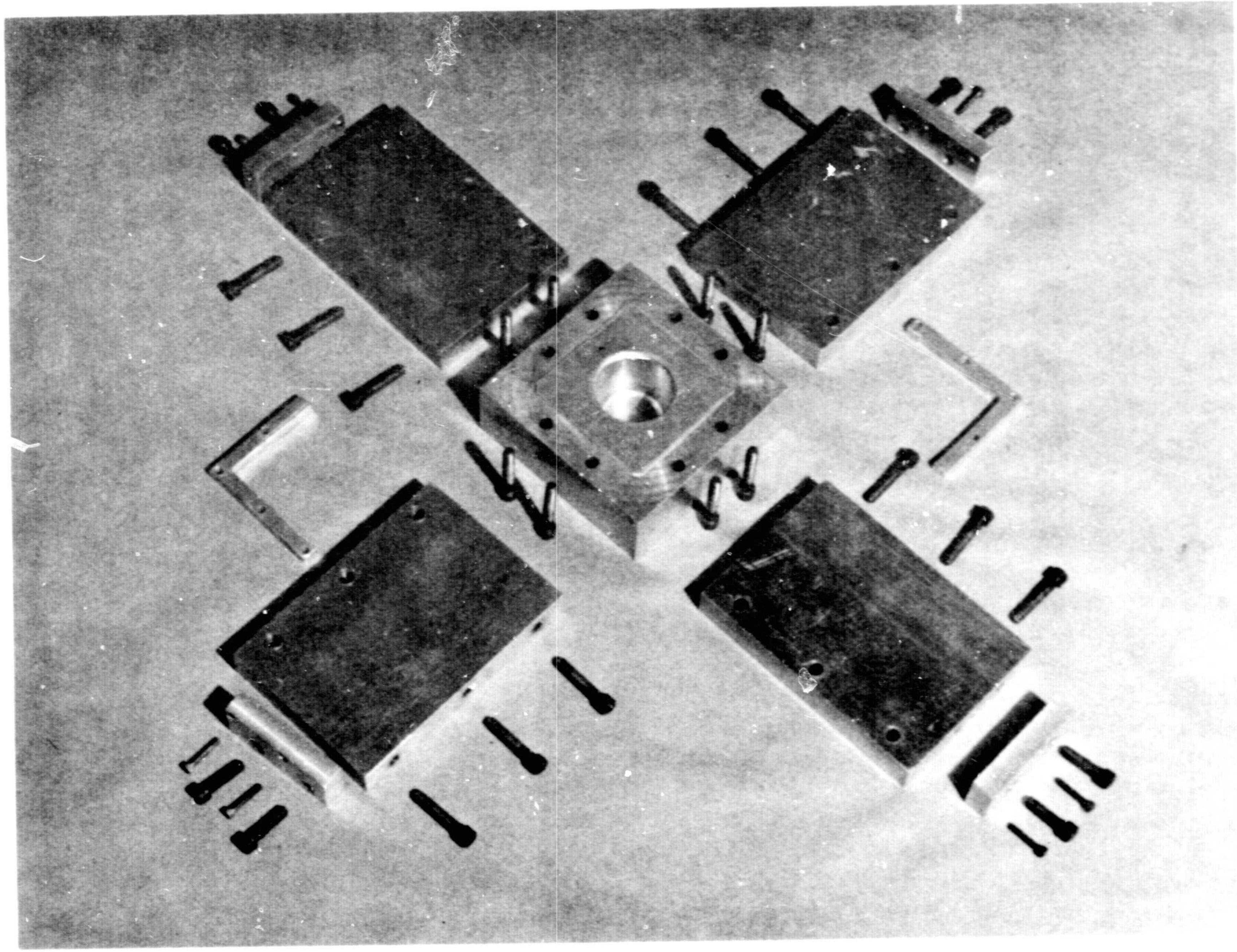

Figure 4.- Dye canister packing fixture.

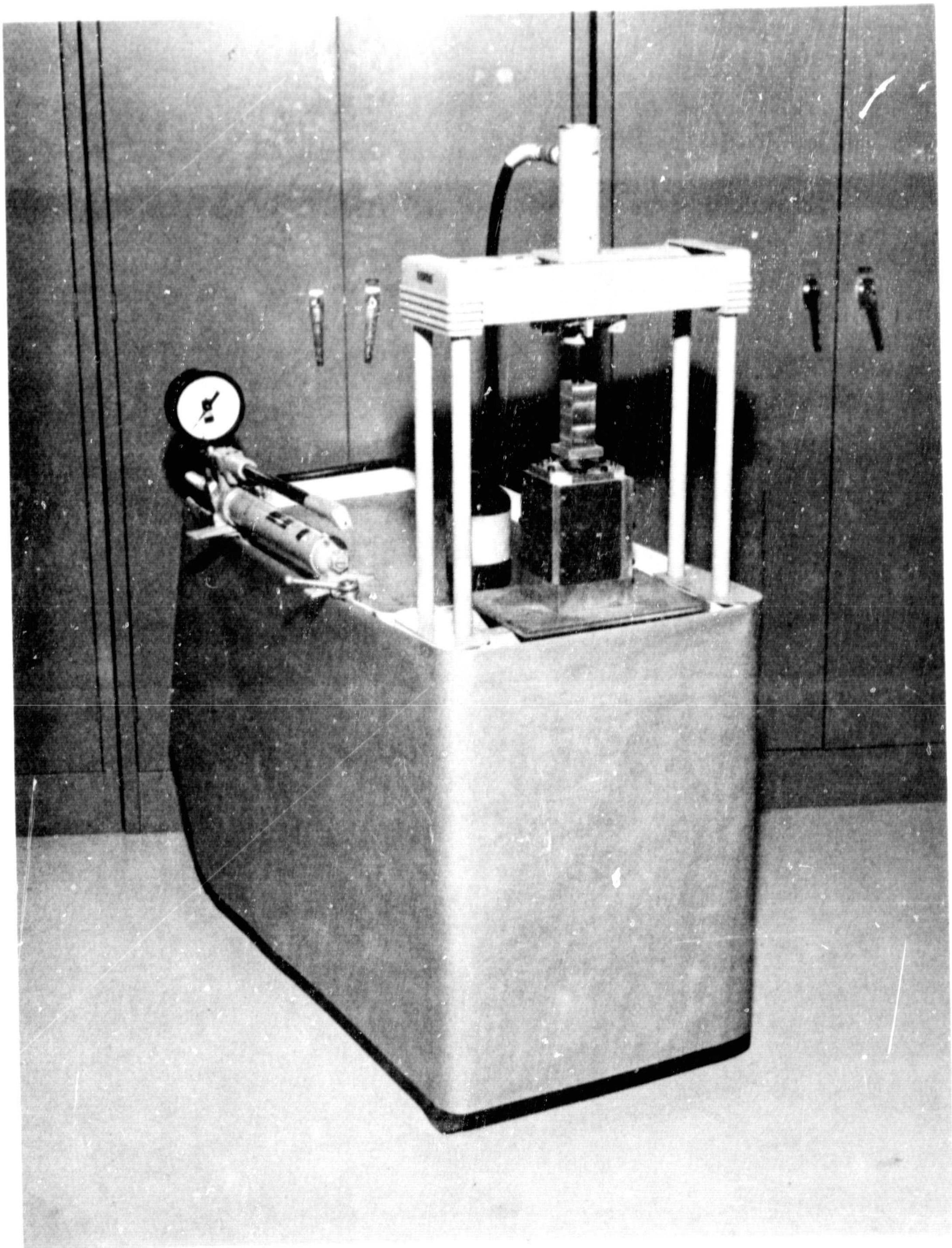

Figure 5.- Assembled packing fixture and hydraulic ram.

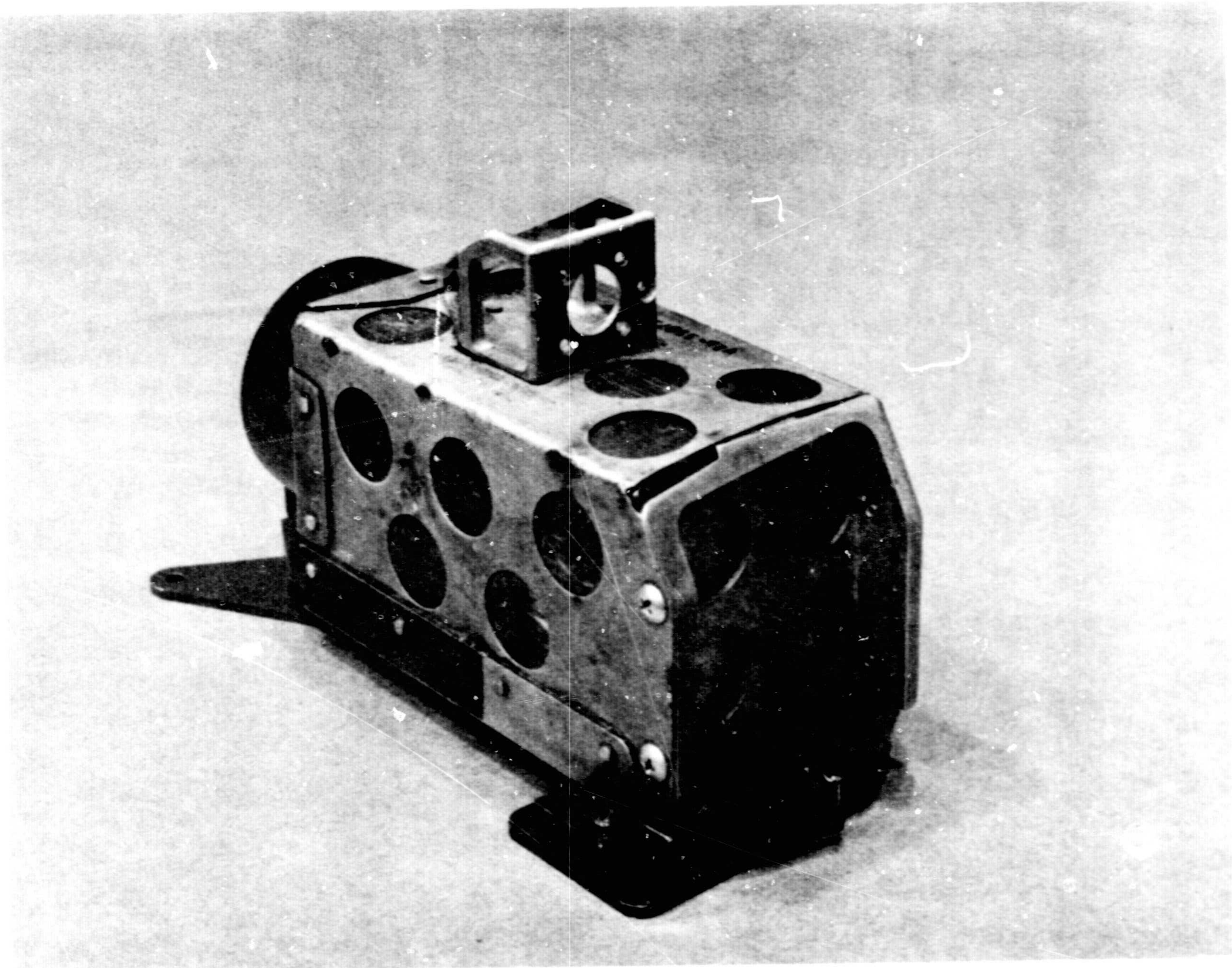

Figure 6.- Dye marker holder.